Theoretic analysis of all-optical wavelength converter based on single-port-coupled SOA

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Abstract: Novel all-optical wavelength converter (AOWC) based on cross gain modulation (XGM) in single-port-coupled semiconductor optical amplifier (SOA) was proposed, and a dynamic model was presented. Based on the dynamic model, factors which affect output extinction ratio and converted signal chirp, such as signal power, probe power were analyzed respectively. The novel scheme using single-port-coupled SOA was compared with the scheme with traditional SOA. Results showed that converted signal chirp decreased and output extinction ratio was promoted by exploiting single-port-coupled SOA.

Keywords: Semiconductor Optical Amplifier (SOA); Cross Gain Modulation (XGM); All-optical Wavelength Converter (AOWC); Chirp; Extinction Ratio (ER)

1 Introduction

Semiconductor optical amplifiers (SOAs) based on cross gain modulation (XGM) have been widely studied as a possible way to serve as wavelength converters because of simple implementation, high conversion efficiency and large wavelength conversion span[1], but traditional wavelength converters consist of double-port-coupled SOA (e.g., one port acts as input port, the other does output port) which not only need exigent fabricating technics for the residual reflectivity must be very low ($<10^{-6}$), but also exist the extinction ratio degeneration in wavelength up conversion[2]. In the literature [3], novel scheme for XGM wavelength conversion based on single-port-coupled SOA is proposed. Experimental result shows that its extinction ratio is better than that in traditional schemes based on double-port-coupled SOA, however theoretic model is absent. In this paper, dynamic model will be presented and based on the model the performance of extinction ratio and chirp will be analyzed respectively.

2 Model

In the literature [3], experimental setup for novel wavelength conversion scheme is depicted in Fig. 1. Continuous wavelength (CW) probe signal and the pump signal are multiplexed by multiplexer, then the multiplexed optical signal is coupled into the SOA by the circulator via port 2. The polarization controller is set before the SOA to control the polarization state of input signal. The rear facet of SOA is coated with 10^{-2} order anti-reflective (AR) film. The reflected optical signal from the rear facet of the SOA can be taken out through port 3 of the circulator. The tunable bandpass filter is used to select out the converted signal from the mixed signal. The variable attenuator is used to control the received signal power. The OSA can analyze the probe spectrum and oscilloscope can analyze the probe power.

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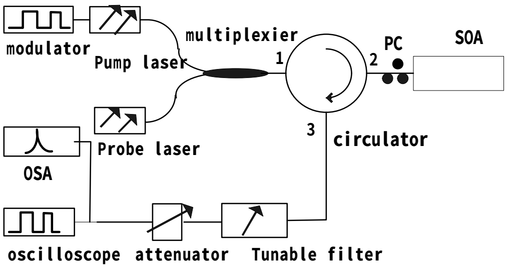

Fig .1 experiment system of wavelength converter based on single-port-coupled SOA

The rate equation can be written by neglecting amplified spontaneous emission (ASE) [4]

$$\frac{\partial N}{\partial t} = \frac{I}{eV} - R(N) - \sum_{i=p,c} \frac{\Gamma g_i(N)}{Ahc/l_i} P_i \qquad (1)$$

when saturation of SOA mainly depends on input optical power, the assumption that ASE power is neglected is reasonable, so the dynamic model in this paper is based on the assumption.

The propagation equations for probe power and pump power can be written as following [5]

$$\pm \frac{\partial P_i}{\partial z} = [\Gamma g_i(N) - a_{in}] P_i \qquad (2)$$

where $i = p, c$ are, respectively, the pump optical and the probe optical. + and – represent the forward and backward propagation. *N* is carrier density, *I* is current, *V* is the volume of the active region, *e* is electron charge, *A* is effective area, *R(N)* is the total recombination rate, and *P* and l are, respectively, the power and wavelength, *G* is confinement factor, a_{in} is absorption coefficient, $g_i(N)$ is gain coefficient.

In order to more effectively model the asymmetric gain, we derive a cubic formula with empirically-determined constants to describe gain coefficient as following [6]

$$g_i(N) = g_N(N - N_t) - r_2(l_i - l_p)^2 + r_3(l_i - l_p)^3 \qquad (3)$$

$$l_p = l_{ref} - k_0(N - N_t)$$

where g_N is differential gain. N_t is transparent carrier density. Λp is the peak wavelength at carrier density *N*. λ_{ref} is the peak wavelength at transparency. k_0 is a constant characterizing the gain-peak shift. r_2 is a constant determining the gain bandwidth and r_3 is a constant accounting for the asymmetry of the gain curve.

The total recombination rate can be expressed as [7]

$$R(N) = AN + BN^2 + CN^3 \qquad \mathbf{(4)}$$

A, B and C are the nonradiative recombination, the spontaneous emission and the Auger recombination terms, respectively.

When optical signal propagate through active region, carrier density will change correspondingly, then the refractive index and phase will change as well. The variation of converted signal phase according to active region length can be described as [8] $\frac{d\Phi}{dz} = -\frac{1}{2}\Gamma ag$ (5)

Then converted signal chirp can be expressed as following

$$\Delta n = -\frac{1}{2p}\frac{d\Phi}{dt} = \frac{1}{4p}\Gamma\int_0^L \left|\frac{da}{dt}g + \frac{dg}{dt}a\right| dz \qquad (6)$$

As for an ideal model of single-port-coupled SOA, the fore facet has the zero-reflectivity and the rear facet coats film in order that the reflectivity, r, is not zero (e.g. $0.001 \le r \le 0.1$), which is very different from that of ideal traditional SOA. The subsection model is exploited in this paper. The length of active region is divided into M (e.g. M=10) subsections, and in each subsection the carrier density is uniform. The subsection model can be depicted in Fig. 2.

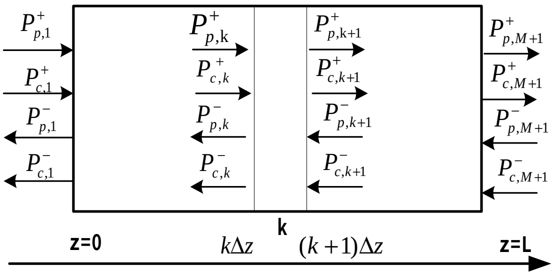

Fig .2 subsection model of single-port-coupled SOA

The backward propagation power in the last subsection depends on forward propagation in that because single-port-coupled SOA can acquire backward propagation power that be gained in the second time by exploiting rear facet's coating film. It can be expressed as $P^-_{i,M+1} = P^+_{i,M+1} \cdot r$ (7).

Where + and – are forward propagation and backward propagation respectively. $i = p, c$ are pump and probe respectively, *M+1* is the last subsection.

First, in order to work out the initial carrier density, static equation is adopted [9], namely, $\partial N/\partial t = 0$. As for an arbitrary subsection *j*, there is

$$\frac{I_j}{eV_j} - R(N_j) - \sum_{i=p,c}\frac{\Gamma g_i(N_j)}{Ahc/l_i}P_{i,j} = 0 \qquad (8)$$

We assume that backward propagation power, $P^-_{i,M+1}$, is a known quantity, and evaluate an arbitrary value. As carrier density of each section is unknown, after evaluating *j* from 1 to *M*, formula (8) turns into a M-dimension group of nonlinear equation, according to (8) carrier density in each subsection can be worked out, and then according to (2) probe power and pump power can be worked out as well. Then according to (7) backward propagation power, $\overline{P^-_{i,M+1}}$, can be calculated. The calculated power $\overline{P^-_{i,M+1}}$ and evaluated power $P^-_{i,M+1}$ are compared. If they are similar or identical, namely, $\overline{P^-_{i,M+1}} \approx P^-_{i,M+1}$, then the assumption evaluated value $P^-_{i,M+1}$ is reasonable and output the result. Otherwise, update the evaluated value $P^-_{i,M+1}$ with $\overline{P^-_{i,M+1}}$, namely, $P^-_{i,M+1} = \overline{P^-_{i,M+1}}$, and recalculate the equations till the judging condition is true.

After working out initial carrier density, formula (1) can be resolved via Runge-Kutta arithmetic and carrier density in whole time can be worked out, then pump and probe power can be worked out according to (2), and then extinction ratio can be calculated and chirp can be computed via (5).

3 Results and discussion

The length of SOA is divided into 10 subsections, and signal pulse is simulated by 3 rank hyper Gauss pulse, and signal rate is 10Gbps. The bias current is 100mA. The wavelength of pump and probe are 1550nm and 1540nm respectively. Rear facet reflectivity is 1%. Performance of extinction ratio and chirp will analyzed below by dynamic model in section 2.

3.1 extinction ratio and chirp versus input power.

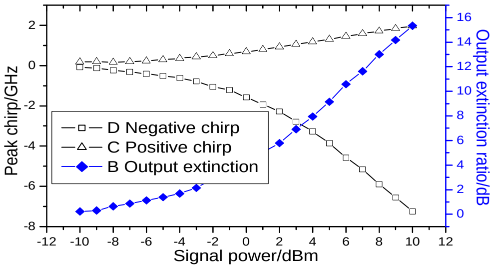

Fig. 3 output extinction ratio and peak chirp versus signal power

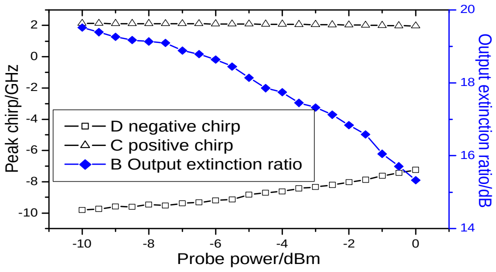

Fig. 4 output extinction ratio and peak chirp versus probe power

Fig. 3 shows that both output extinction ratio and converted signal chirp (peak chirp here) will increase when input pump power increases. If pump power increases, then the variation of carrier density becomes great, so the chirp will increase. In addition, the variation of carrier density increase will lead to variation of gain increasing, so extinction ratio will increase. In Fig. 4, we can see both output extinction ratio and converted signal chirp will decrease with probe power increasing. This is because if probe power increases, carrier consumed by pump power will decrease, as a result, converted signal chirp decreases as well as extinction ratio does. In order to acquire better extinction ratio performance, we need high pump power and low probe power, at the same time, chirp increases as well, so there is a tradeoff between extinction ratio and chirp.

3.2 extinction ratio performance in two schemes

As for ideal double-port-coupled SOA, residual reflectivity is zero, but as for single-port-coupled SOA, rear facet's reflectivity is 1%. Fig. 5 shows that extinction ratio is similar when pump power is low level, but that of novel scheme is much higher than that of traditional scheme. Fig. 6 shows that extinction of novel scheme is much higher than that of traditional scheme. In a word, extinction ratio performance has been greatly improved in novel scheme.

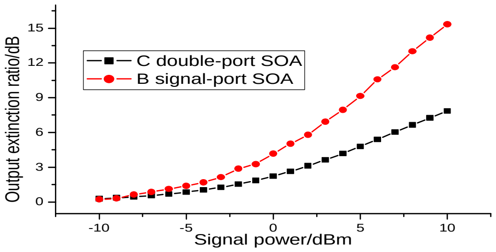

Fig. 5 output extinction ratio versus signal power in two schemes

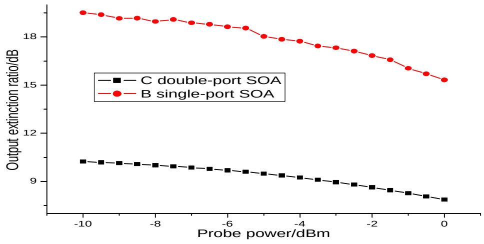

Fig. 6 output extinction ratio versus probe power in two schemes

3.3 chirp performance in two schemes

From Fig. 7, we can see converted signal chirp will increase if output extinction ratio increases. In the condition of identical extinction, chirp of novel scheme is much lower than that of traditional scheme. This is because in order to achieve higher extinction ratio in traditional scheme, bigger pump power and lower probe power are demanded, which are inclined to degenerated chirp performance. In contrast, in novel scheme, we can achieve better extinction ratio by a little low pump power and proper probe power.

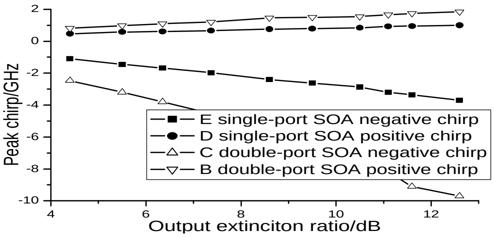

Fig. 7 peak chirp versus output extinction in two schemes

4 Conclusions

Dynamic model about wavelength converter based on single-port-coupled SOA has been proposed. The impact of pump and probe power on extinction ratio and chirp has been analyzed, namely, both the extinction ratio and chirp will increase if probe power decreases or pump power increases. In addition, two schemes have been compared in extinction ratio and chirp and the result shows that novel scheme has much better extinction ratio performance in identical input power level and has much better chirp performance in identical output extinction ratio level.

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